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## **Expert systems: Advanced computer software with potential optometric applications**

### **Abstract**

Expert systems are a form of advanced computer programming utilizing aspects of artificial intelligence to emulate the skills of an expert within a given field of knowledge. Low cost expert systems are now being used in business, and soon will be seen in some health professions. This article describes the basics of expert systems, and suggests possible applications in optometry.

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
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EXPERT SYSTEMS: ADVANCED COMPUTER SOFTWARE  
WITH POTENTIAL OPTOMETRIC APPLICATIONS

Pacific University College of Optometry  
May 1987

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Fred Downard was born in Lima, Ohio and has always had a strong interest in computers and robots. In 1969, while in Ohio, he went on to the regional Science Fair by reporting on robots and computers. As an undergraduate, he studied computer languages while pursuing a major in Zoology and a minor in chemistry.

Sandy Berry is a resident of Seattle, Washington. He has had an interest in science and technology since childhood. In seventh grade he build a digital computer to play tic-tac-toe. "It was before inexpensive semiconductors, so all the logic had to be literally hard wired!". He is a graduate in Botany from the University of Washington, where he worked as a Bio-scientific photographer in both the department of Botany and the department of Neurological Surgery. He is a co-discover of a new genus and species of slime mold.

## ABSTRACT

Expert systems are a form of advanced computer programming utilizing aspects of artificial intelligence to emulate the skills of an expert within a given field of knowledge. Low cost expert systems are now being used in business, and soon will be seen in some health professions. This article describes the basics of expert systems, and suggests possible applications in optometry.

KEY WORDS- computer, information systems, artificial intelligence, computer diagnosis.

## INTRODUCTION

Today computers are becoming more commonplace in optometric settings. With doctors becoming more familiar with their use for general office management tasks such as accounting and patient recall, it is natural for an optometrist to wonder what else the computer can do for him or her. Research in computer science over the past twenty years has suggested that computers may be able to simulate the reasoning abilities of the human mind. This is the field known as ARTIFICIAL INTELLIGENCE (AI). An interesting subset of the large field of AI is the area known as EXPERT SYSTEMS. Expert systems are computer programs which attempt to distill the analytical reasoning abilities of a human expert dealing with problems in a specialized field. Optometry is a specialty which may lend itself to description by such expert systems. Since micro-computers are becoming less expensive, more powerful and AI influenced programs are becoming available to the health professions, how can the potential interpretative abilities of such expert computer systems impact optometric practice? This question will be explored, as we define artificial intelligence, survey an example expert system, dissect the building blocks of expert systems, and ponder possible optometric implications of expert systems. (1,2)

## ARTIFICIAL INTELLIGENCE

Artificial intelligence is the study of making a computer do things which, at present, human beings can do better. This definition has historical roots in the field of cognitive psychology, as many early AI researchers were psychologists who were interested in emulating the human mind process via step wise mimicing of supposed brain functions and cognitive processes. Others in AI were interested in getting the computing machine to do what a human does, not how a human does it. These researchers prefer to describe what they study as MACHINE INTELLIGENCE rather than ARTIFICIAL INTELLIGENCE. As can be imagined, defining intelligence has been the subject of much debate, but a general definition of intelligence may be "the ability to learn or understand from experience and pattern an appropriate response to a novel environment". Intelligent behavior thus requires the ability to make sense of ambiguous stimuli and recognize the relative importances of different parts of the environment. This involves evaluating similarities and differences within previously experienced situations and formulating sets of rules, expectancies or generalities which can be applied to new situations. Can mere computer computation equal this human behavior?

In some ways, a computer is superior to a human. Areas of raw numerical calculation, information storage, and repetitive operations are better performed by computers. In addition, they are not subject to fatigue, ordinary memory loss, or cost of living adjustments. Traditional computer usage has exploited these capabilities, because designing "common sense" into computing languages has been anything but simple. Humans still excel at



"common sense" reasoning, easily adapting to different situations by utilizing various strategies.

In trying to create AI programs, some researchers have attempted to simulate these problem solving strategies. Humans learn from past experiences, and infer short cuts to solving problems so that all possibilities do not have to be re-evaluated every time a similar problem needs to be solved. These "rules-of-thumb" are called HEURISTICS. In addition we utilize immediate feedback to test our tentative hypotheses which allows fine tuning of our learned strategies even while the problem is being solved. In contrast, conventional computer programs utilize ALGORITHMS rather than heuristics to solve problems. Algorithms are stepwise procedures which have a specific beginning and a guaranteed result given the incoming data. Mathematical formulae are a type of algorithm.

In the every day world, however, humans receive stimuli from the environment that are subject only to relative certainty, not absolute certainty. Nonetheless, human intelligence copes with the uncertainty of data, and still renders a judgement via heuristic reasoning strategies. In an effort to develop machine intelligence analogous to human reasoning, AI has attempted to develop heuristic style problem solving approaches using "pattern matching" and "best pathway" approaches to problem solving.(2,3)

The area of AI application which interests many people today is the use of AI principles in the form of expert systems. Expert systems attempting to simulate clinical problem solving have appeared in medicine and dentistry. Many important features of an expert system applied to a clinical setting are seen in the program called MYCIN.

## MYCIN: AN EXPERT DIAGNOSTIC SYSTEM

Mycin is an early prototype expert system developed as an infectious blood disease diagnostic program. Developed in the 1970's at Stanford Medical Center, it incorporates the expertise of many doctors skilled at infectious blood diseases. It is designed to offer advice on the possible etiology of an infectious disease and recommend possible treatments, after important clinical findings are entered into the computer. Like many expert systems, it can reach a diagnosis with incomplete or uncertain data, after asking every possible relevant question and having searched through large amounts of supporting data. Mycin interacts with the consulting doctor in a plain english dialog of questions and answers, relieving the doctor of the need to learn a special computer language in order to use the expert system. This aspect is called a NATURAL LANGUAGE USER INTERFACE. Mycin is like many expert systems in that it can explain why it reached a given answer if asked to do so. This allows the computer user to check the reasoning of the system, and offers a useful learning experience to novice interns seeking the advice of a computerized "expert".

In addition, mycin assigns confidence levels to its results, allowing reliable diagnosis from uncertain pieces of clinical evidence. Since many clinical situations produce multiple possible solutions, Mycin lists a ranking of several possible diagnoses along with the most appropriate treatment regimen. Mycin illustrates several qualities of expert systems: many possible solutions, uncertain data, problematic conclusions, and important need to reach a decision. Areas where expert systems are best utilized are areas which lack a complete theoretical framework or in which experts disagree on methods and procedures in solving a problem. This is the

"schools-of-thought" problem which experts in various fields, including optometry, are bound to encounter. Mycin has been an attempt to achieve computerized clinical expertise, despite the variations of "clinical wisdom" and "schools-of-thought" which the problem area inherently possesses. In many ways, programs such as Mycin show significant differences when compared with conventional software programs such as databases and other common applications.

#### CONVENTIONAL SOFTWARE VERSUS EXPERT SYSTEMS

Standard software has abilities to search information in databases and perform amazing feats of mathematical processing. What it lacks is common sense- the user must direct inquiries and interpret findings. Standard programs have linear sequences of instructions with problem logic reduced to simple routines or formulae. Although a conventional database may include vast amounts of information, it is nonetheless unintelligent. It lacks the qualities of automatic inference built into the structure of the data which, in contrast, is inherent in an expert system's knowledge base. A common database program essentially is not a problem solver, but rather a sophisticated fetching mechanism for pre-existing information. The relative importance of the resulting information output is an interpretive act of the user, not the computer program.

Conventional software usually possesses these attributes:

- 1) FOR A GIVEN SET OF DATA THERE IS ONLY ONE POSSIBLE SOLUTION
- 2) A COMPLETE DATA SET IS NEEDED IN ORDER TO DETERMINE AN ANSWER
- 3) DATA INPUT FOLLOWS A REGIMENTED, LINEAR ORDER
- 4) PROBLEM LOGIC IS IN THE FORM OF ALGORITHMS
- 5) A GIVEN VALUE IS ASSUMED TO BE CERTAIN
- 6) MODIFYING THE PROGRAM IS DIFFICULT
- 7) THE GENERAL PROBLEM PARAMETERS CHANGE LITTLE OVER TIME

Figure 1. On the reverse side

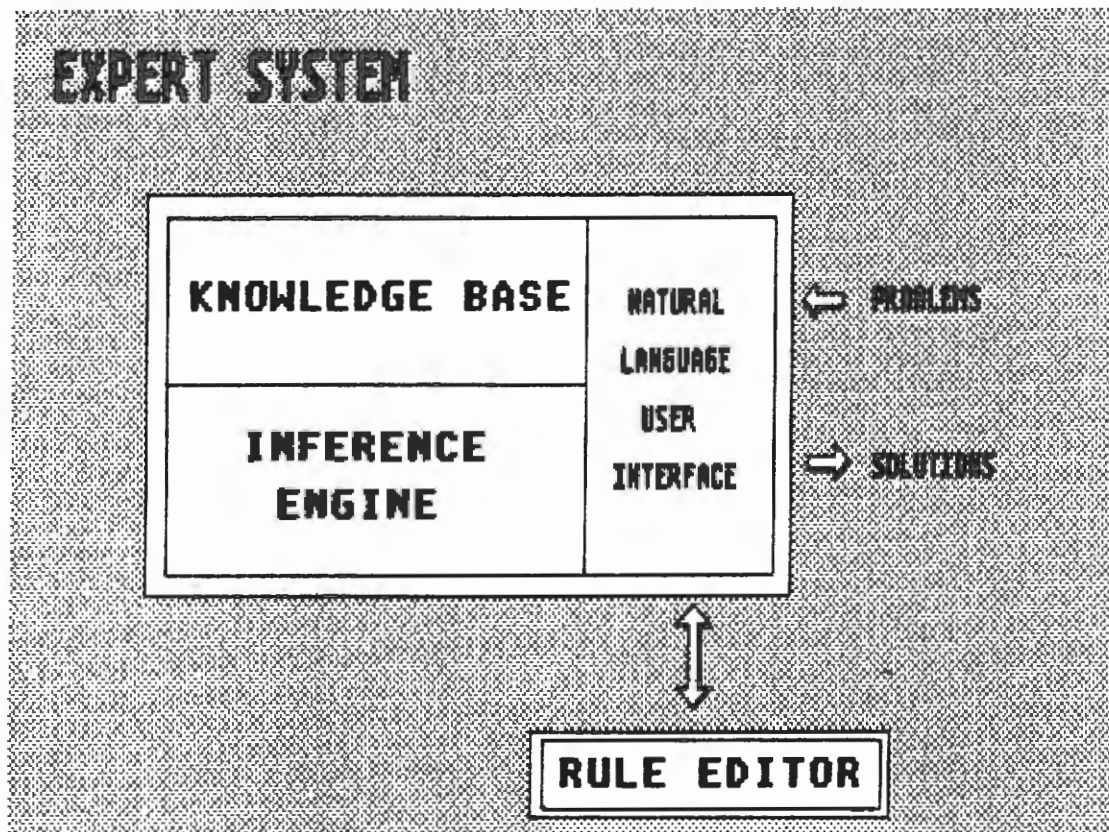


Figure 1. Interrelationship of Expert System Components.

- 8) A COMMONLY ACCEPTED PROTOCOL EXISTS FOR SOLVING THE PROBLEM
- 9) THE PROGRAM IS NOT CAPABLE OF LEARNING, OR MAKING INFERENCES ABOUT INPUT DATA

Expert system software generally has these attributes:

- 1) MULTIPLE SOLUTIONS ARE POSSIBLE FROM A GIVEN DATA SET
- 2) SOME SOLUTIONS POSSIBLE, EVEN WITH INCOMPLETE OR UNCERTAIN DATA
- 3) DATA MAY BE ENTERED IN VARIOUS ORDERS OF SEQUENCE
- 4) PROBLEM LOGIC UTILIZES HEURISTICS AND PROBABILITY FACTORS
- 5) THE GENERAL PROBLEM SHAPE CHANGES OVER TIME
- 6) PROGRAM MAY EASILY BE MODIFIED BY CHANGING KNOWLEDGE RULES
- 7) THERE IS NO "BEST" PROTOCOL FOR SOLVING THE GIVEN PROBLEM
- 8) PROGRAM CAN MAKE NEW INFERENCES, AND MAY SIMULATE SIMPLE LEARNING
- 9) PROGRAM MAY REQUEST ADDITIONAL INFORMATION FROM USER
- 10) A NATURAL LANGUAGE QUESTION AND ANSWER SYSTEM OF INFORMATION EXCHANGE IS USED BETWEEN THE USER AND COMPUTER.

## EXPERT SYSTEMS

An expert system is a computer program using knowledge and reasoning generally requiring the abilities of human experts. It is often configured in several components: a knowledge base, an inference engine, a rule editor and a user interface. (see Fig.1) The knowledge base contains specific facts and heuristics (rules-of-thumb) associated with the area of expertise. The inference engine contains logic procedures for using the knowledge base in the solution of the problem. The user interface is a display and information system for the human operator to use in communicating with the working program. It includes a working database for keeping track of the problem status, the input dialog for a particular consultation session, and the relevant history of what has been input and inferred so far. The rule editor is an optional component

allowing changes to be made to the rules of the knowledge base, should the encoded expertise require updating or fine tuning.

The creation of a knowledge base requires a method of symbolic knowledge representation. Two methods are commonly used in expert programs today: model based, and rule based knowledge representation. The total collection of pertinent facts and procedures needed to apply expertise is called the problem domain. Model based systems contain an internal model of the behavior of the problem domain. This requires a thorough understanding of the dynamics of the problem domain, based upon knowledge of the structure and behavior of the system being considered. Model based systems may have a blend of algorithmic, heuristic, and statistical descriptive components. Portions of knowledge which are well understood may be represented as formulae in a conventional manner, while heuristic connections may be used where algorithms don't exist.

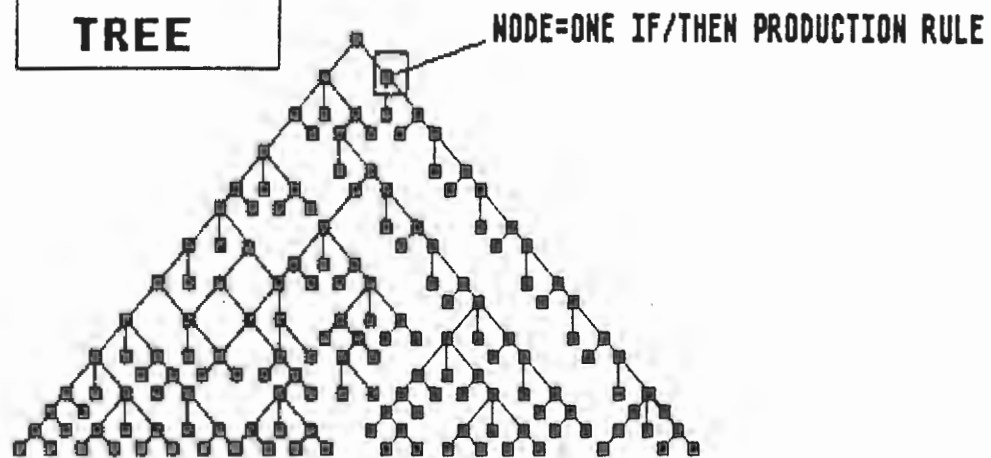
An advantage of a good model based system, is that it is applicable to many variations of the problem. A repair manual for a given type of car may be useless for another make of car. However, a basic knowledge of automobile mechanics makes troubleshooting different cars possible. Following this analogy, a model based representation of knowledge offers a powerful paradigm which allows generalization to a variety of different (but related) situations.

The use of statistical population norms has been a common method used in optometry to build a basic model of visual functions. The tables of expected norms are a codification of visual behavior, and in some cases they have even been refined using age adjusted norming. It can be argued that comparison of optometric data against population norms represents a basic level of expertise in the interpretation of findings. Recently, the automation of

Figure 2. On the reverse side



## DECISION TREE



- THE DECISION TREE IS THE BRANCHING PATTERN OF INTERCONNECTED IF/THEN PRODUCTION RULES FORMING NODES IN THE MATRIX.
- THE COLLECTION OF BRANCHING PATHS REPRESENTS THE SEARCH SPACE.
- THE TOTAL UNIQUE IF/THEN PRODUCTION RULES ARE THE KNOWLEDGE BASE.
- A GIVEN RULE MAY BE LOCATED AT SEVERAL NODES IN THE TREE.

**PROBLEM ⇒ TREE SEARCH ⇒ SOLUTIONS**

Figure 2. Example of a Decision Tree.

SEARCH SPACE. Much of the history of AI has been devoted to determining efficient search techniques and methods useful in limiting the search space. A graphical representation of a search space is a branching network called a SEARCH TREE or DECISION TREE (Fig.2). The individual components are the IF/THEN production rules of the knowledge base. Since many rules are connected to each other, a search strategy must be established to limit the almost infinite possibilities of combinations that could be used in searching for a solution to the input problem. It is for this reason that many problems are not well suited to conventional software programs that must use fixed algorithms. Using the game of chess as an example, even though the rules of play are algorithmic, searching every possible combination of moves creates what is called a COMBINATORIAL EXPLOSION. Even the fastest supercomputers could not win at chess using only algorithms and a complete search of every possible move each time it was the computers turn to play. In expert systems, the search strategy of which rules to invoke, and when to stop a search in a given branch of a decision tree, is governed by a portion of the expert system called the INFERENCE ENGINE. A great deal of the heuristics of the system are instilled in the INFERENCE ENGINE, as it can make "rules-about-rules", and can determine new inferences for a given knowledge base. It functions as the "common sense" of the system, and traffic controller for the logic searches. A well conceived inference engine has the advantage that it is transportable: it may be used with different knowledge bases, forming different expert systems. This aspect, has led to the development of EXPERT SHELL SYSTEMS which are software development programs having a generic inference engine, user interface and a KNOWLEDGE BASE EDITOR. The knowledge base editor allows the developer to construct

a knowledge base of IF/THEN production rules which may then be processed using the system's inference engine.

The knowledge bases form removable "shells" around the inference engine. The substitution of one knowledge base for another can create a totally different "expert system" around the same building blocks of the initial "expert system kernel" which includes an inference engine, and a user interface. The removal of the knowledge base editor from a system, creates a "turn-key" expert system with only one knowledge base. This effectively removes the possibility that the knowledge of the system might be corrupted by a naive user attempting to modify the facts and heuristics of the system. Commercial applications may come as both turn-key systems or as knowledge base modules connected to a central inference engine/user interface kernel. In contrast, a development kit would by definition include a knowledge base editor for creation and maintenance of a knowledge base.(4,5,6)

## SEARCH TECHNIQUES

Given that one has a knowledge base connected to the other components of an expert system, how is the system used to solve problems? The solution of problems involves the orderly searching and testing of various hypothesis represented in the knowledge base rules. There are several search techniques in common use but none are guaranteed methods to produce the most efficient search to the best solution .... or to produce any solution at all. Yet they are used as rules-of-thumb (heuristics) to prevent an extensive "blind search" which is prone to the combinatorial explosion problem. During each search, every move leads to several possible new

Figure 3. On the reverse side

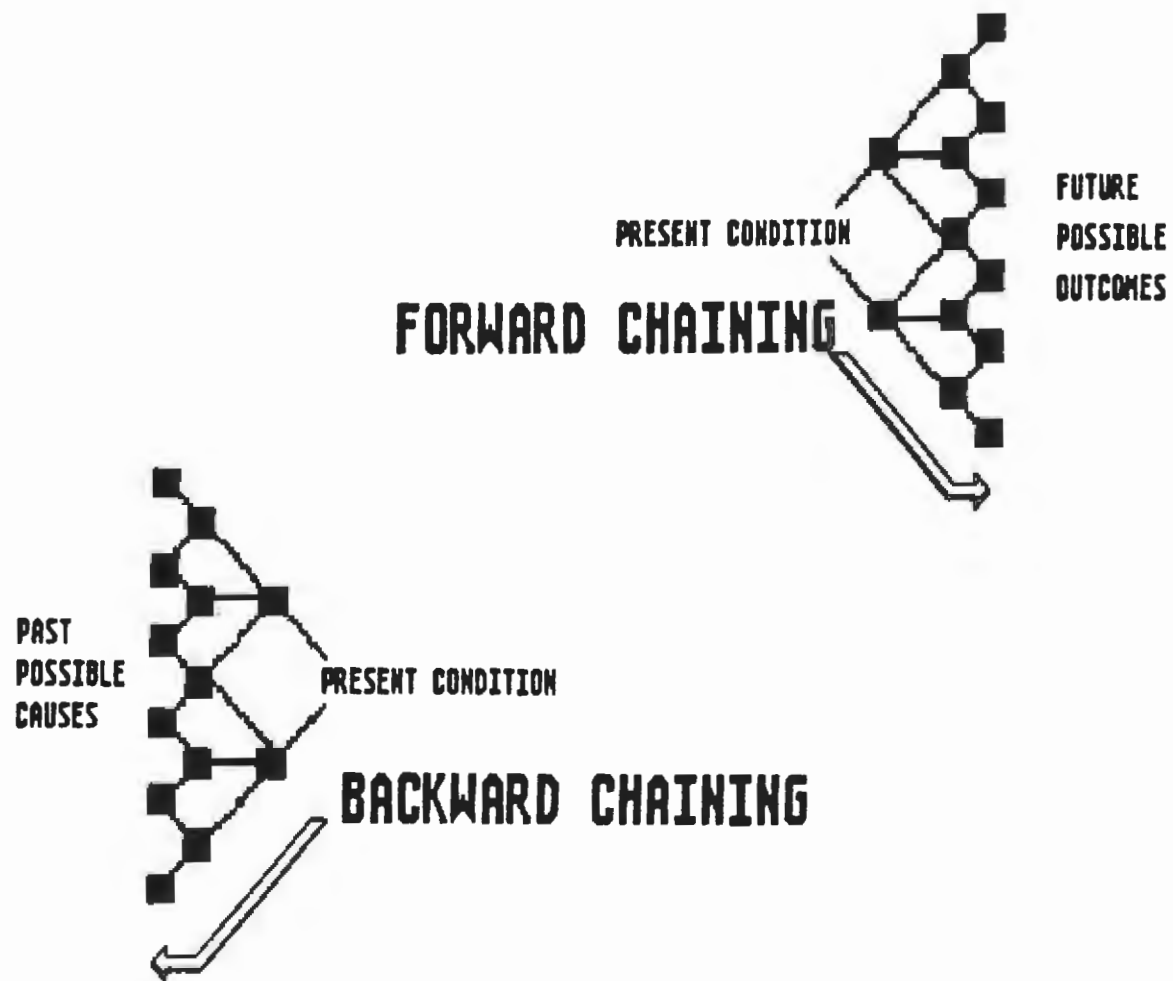


Figure 3. Examples of Forward and Backward Chaining.

possibilities represented by interconnections to the current node of the search tree. A node is a given IF/THEN production rule from which decision branches appear in the search tree. The "level" of search may represent all the nodes that are an equivalent number of "moves" from the start. A "breadth-first" strategy would search all the nodes of the same level for a possible solution, before moving to deeper levels. A "depth-first" search, would search through multiple levels along one branch of the search tree. If the final solution (goal) is many levels deep from the initial state, then a breath-first strategy is computationally very inefficient. In a depth-first strategy, search continues until a solution is found or a deadend is encountered which then requires searching along another branch.

In addition to these methods, searches may be driven in one of two directions along a logical time line. They may procede from an effect to its cause (BACKWARD CHAINING), or from a present condition or problem to a possible future condition or solution (FORWARD CHAINING),(Fig.3). The nature of the problem needing solution indicates the type of chaining strategy which is most appropriate. Backward chaining is typified by having many possible antecedents for a given present condition (i.e. etiologies of diseases, diagnosis), whereas forward chaining has limited present conditions and many possible future outcomes, (i.e. predictive processing). In everyday reasoning, one uses a combination of both forward and backward chaining to elucidate the scope of a problem by examining both possible causes and predicting probable effects. This is called MIXED CHAINING or BIDIRECTION CHAINING. All of these chaining strategies may be utilized in an expert system. Problems emphasizing backward chaining benefit from the ability of expert systems to

explain their reasoning. Forward chaining cannot explain its reasoning, but may list assumptions and assign probability factors to a prediction.

## FUZZY DATA AND FUZZY LOGIC

The imprecision of real world data, and the need to reach conclusions based upon uncertain premises has lead AI researchers to develop methods to account for the problems of "fuzzy data" and "fuzzy logic". Each IF/THEN production rule contains not only facts (the IF side) but also predictions (the THEN side). Since each production rule is a rule-of-thumb, the complete correspondence of a given rule with reality is unlikely. Combining this uncertainty with the uncertainty of all the other connected rules creates a problem of confidence levels. Rule based systems have coped with this by assigning confidence factors to each outcome derived from a given rule. The output from a given production rule may potentially lead from a minimum of two, to possibly many outcomes. Each outcome may have a different probability of occurring, and therefore an appropriate certainty weighting may be assigned. This allows the inference engine the option of using a search strategy which examines "most-likely" routes to a solution first; more common possibilities are examined before rare ones. In addition, multiple possible solutions may be ranked based on their relative probabilities by calculating the accumulative weight factors for each branching route to a particular solution. The raw score weights may be compared in multiple outcome situations, and a relative ranking determined. In this way, the expert system simulates the "clinical" or "professional" judgement of a human expert. The certainty factors, like other production rule aspects, may be adjusted through the use

of the knowledge base editor to fine tune the predictive or diagnostic abilities of the system.

#### PROBLEMS RELATED TO CLINICAL EXPERT SYSTEMS

In using a clinical expert system, there are several potential problem areas: development costs, clinician usage problems, medicolegal considerations, and patient acceptance.

Developing an expert system is a long and expensive process. Mycin took fifteen to twenty-five man years to develop and has 500 rules governing it. A developer must have a large enough potential market to justify the considerable effort. The hardware of the microcomputers are certainly powerful and inexpensive enough now to handle some expert system uses, and will only become better in the near future, yet optometry and ophthalmology may not represent a large enough market to justify the design of vision related expert software systems. Development packages for expert system design will become more readily available and easier to use, but for at least the next several years will still involve a programmer (knowledge engineer) to develop a useful system. (7,8)

A clinician considering using an expert system is confronted with several questions. First, several aspects of the expert system must be examined. Can the internal logic of the program be examined by the consulting doctor? Can the program explain its reasoning? Can the doctor inference rules or amend the knowledge base? Is the style of case analysis offered by the expert system in agreement with the practitioner's own style? Would the system reach similar or better conclusions than the doctor, given the same clinical findings? Secondly, there are considerations concerning the use of any computer system and software. Is the



time needed to enter information into the computer system worth the benefit as measured by improved clinical accuracy and efficiency? How secure is the information? Can information files be tampered with, or inadvertently destroyed? Does the doctor understand the limits of the expert program? And thirdly, there are potential ethical and philosophical questions. If much of the clinical diagnosis is automated, what job is left to the doctor? Who bears the medicolegal responsibility using advice from an expert system? How much liability do the software designers bear, how much do the doctors bear?

The success of patient interactions with computer analysis have been and continue to be mixed. The human to human empathy between doctor and patient is very important, and while some patients may look upon all technological innovation favorably, some may resent it.

#### ADVANTAGES OF EXPERT SYSTEMS

Expert systems offer several critical advantages. An expert system could suggest areas to further investigate in a perplexing case. An expert system could be updated with the latest knowledge base via periodic updates. An expert system is equally methodical in every case, unlike their human counterparts. It is possible that widespread use of expert systems and automated instruments could lead to a change in the standard of care expected of the profession. It may lead to not only more findings gathered per patient, but also to more conclusions routinely drawn from the given data.

In optometry, areas suggestive of expert system implementation include: special contact lens fitting, drug interactions and therapeutics, vision therapy diagnosis and treatment, automated visual field interpretation, digital fundus image analysis,

differential pathological diagnosis, "reference librarian" system for database management, accounting and tax planning, and of course, general case analysis. From this list, it is easy to see that many applications in optometry could potentially be touched by the machine intelligence of expert systems. (8,9,10)

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